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SOCIO-ECONOMIC VALUE OF CLIMATE FORECASTS

Report

to

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Contents

Part I

Overview of the Literature

Introduction

Part I consists of an overview of the existing literature on the socio-economic value of climate forecasts. The overview includes sections on approaches to and methods of forecast-value assessment, the results of forecast-value case studies and other closely related work, and some tentative conclusions together with a short list of current problems.

Overview of the Literature

This brief overview of the literature on the socio-economic value of climate forecasts is organized into the following sections: (1) approaches taken and methods used to assess the value of climate forecasts; (2) results of case studies and other assessments of the socio-economic value of these forecasts; and (3) a catalogue of outstanding methodological and practical issues and problems.

It is necessary first to identify the scope of the body of literature which is reviewed here and which is listed in Parts II and III of the report. Although the primary focus of the report is the socio-economic value of *climate* forecasts, relevant items from the literature on the value of weather *and* climate forecasts have been included. This decision was based primarily on the fact that similar assessment methods have been used - and the same types of forecast-value studies have been conducted - across the entire spectrum of forecast time-ranges (from day-to-day weather forecasts to monthly or seasonal climate forecasts). Moreover, the results obtained and lessons learned from studies conducted in one part of this spectrum often have clear implications for work contemplated in other parts of the spectrum.

The focus of this overview is the socio-economic *value of climate forecasts*, not the socio-economic impact of climate. Thus, the relatively large and rapidly growing literature on the latter topic generally is excluded from consideration here. A few exceptions have been made in the cases of papers or reports that while primarily concerned with socio-economic impacts either touch directly upon forecast-value issues or appear to have important implications for such issues.

In compiling the list of references, primary emphasis has been placed on papers and reports published during the last 20 years (since the early 1970s). Only landmark items from the 1960s are included and no papers or reports are cited for earlier periods. The early papers are now largely of historical interest only; the reader interested in this early literature (i.e., pre-1970) can find references to it in some of the publications cited here.

A. Approaches and Methods of Forecast-Value Assessment

Two general approaches to the problem of assessing the socio-economic value of climate forecasts can be identified: (1) the prescriptive approach and (2) the descriptive approach. The prescriptive approach assumes that users of such forecasts behave in a manner consistent with normative principles (e.g., the maximization of individual or collective economic welfare). This approach involves the use of formal models of individual users' decision-making problems or of economic markets (or sectors) influenced by the aggregate effects of individual users' decisions. The descriptive approach, on the other hand, focuses on the actual behavior of users (i.e., their actual information-processing and decision-making procedures). Formal models of the type employed in the prescriptive approach are generally not employed in the descriptive approach. However, the latter may involve the use of conceptual or behavioral models of users' climate-sensitive problems and/or the ways in which they perform their information-processing and decision-making tasks.

These approaches can be applied at the level of individual users or at the level of markets consisting of groups of individual users who face similar decisions and/or participate in similar activities. At the individual-user level, assessments associated with the prescriptive approach generally employ decision-analytic methodology. This methodolgy involves *(inter alia)* formulating a model of a user's decision-making problem (identification of the user's feasible actions and definition of the relevant climate events, determination of the socio-economic consequences of various action-event combinations, etc.), modeling or describing the quality of the forecasts, and specifying a criterion according to which the user will choose a preferred course of action. In some cases these decision-making problems involve a single decision (or a set of similar but independent decisions), whereas in other cases they involve a sequence of interrelated decisions. The former are referred to as single-stage (or static) problems, whereas the latter are referred to as multiple-stage (or dynamic) problems.

At the market level, prescriptive assessments usually employ methods based on economic concepts such as producer and consumer surplus and/or rational expectations. These methods attempt to address directly the ways in which climate forecasts affect market-level factors such as the price of a commodity produced by individual users of the forecasts as well as the socio-

economic welfare of both producers and consumers of the commodity. In these market-level assessments, climate forecasts are taken to represent a technological advance, and their value (whether positive or negative) is inferred from the equilibrium situation that results when the market for the commodity adjusts to the presence of this new technology.

Assessment methods associated with the descriptive approach range from surveys of (and/or interviews with) users to in-depth case studies and decision experiments. In the case of surveys and interviews, the information required to *(inter alia)* infer forecast-value estimates is sought via users' responses to direct or indirect questions. Case studies and decision experiments generally involve relatively detailed monitoring and possibly conceptual modeling of users' behavior in forecast-sensitive situations and/or experiments in which users make forecast-sensitive decisions under realistic but controlled conditions.

Application of prescriptive or descriptive assessment methods to forecast-sensitive situations usually involves assumptions regarding the nature or structure of the underlying situations and/or the behavior of users of the forecasts (especially in the case of assessments based on prescriptive methods). Frequently, legitimate questions can be raised about the appropriateness of these assumptions, as well as about the reliability of forecast-value estimates derived from these applications. In the case of methods associated with the prescriptive approach, questions may arise as to whether the models capture all of the essential features of the underlying situations and whether the behavior of individual users - or its collective impact at the market level - is characterized properly. With regard to methods associated with the descriptive approach, the reliability of users' responses to questions posed during surveys or interviews may be open to question, especially in those situations in which the interview/survey questions are not framed adequately or are not "rooted" sufficiently in the users' forecast-sensitive situations. Moreover, inferences drawn from users' behavior can be misleading if the reasons for this behavior are not well understood, and the behavior of users in the real world may differ from their behavior in experimental settings.

These problems can be overcome to a considerable extent - and the reliability and credibility of forecast-value estimates could be improved substantially - by taking advantage of

the full range of capabilities contained in existing assessment methods. For example, decision-analytic methods explicitly allow for the consideration of users' attitudes to risk, yet most prescriptive forecast-value studies conducted to date have assumed that users are risk neutral. Moreover, assessment methods based on economic principles are available that can provide aggregate estimates of the benefits of forecasts at the market-level, yet most forecast-value estimates at the level of markets or sectors have been based on scaled-up estimates obtained at the level of individual users. In a related vein, well-designed and carefully conducted surveys or case studies, in addition to providing a sound basis for making descriptive forecast-value assessments, can serve as an important source of information for - as well as a reality check on the assumptions made, models formulated, etc., in - prescriptive assessments. Generally speaking, the best forecast-value studies are those that attempt to make use of the full range of features associated with both prescriptive and descriptive assessment methods.

The determinants of forecast value also depend on the approach that is taken and/or the assessment method that is employed (or at least the level at which the assessment is made). At the level of the individual user, the prescriptive determinants of forecast value are: (1) the courses of action (or strategies) available to the user; (2) the user's payoff or loss function; (3) the quality of the information on which the user's decisions are based in the absence of the forecasts; and (4) the quality of the forecasts themselves. It is important to note that, in this context, forecasts that lead a user to take the same actions that he/she would have taken in the absence of the forecasts are of no value. At the market level, considerations such as supply/demand elasticities and shifts in supply and demand curves may influence forecast value. When a descriptive approach is followed, the list of determinants of forecast value also includes various behavioral characteristics of the users.

B. Forecast-Value Case Studies and Related Work: Some Results

Prescriptive studies generally have focused on the value of forecasts at the level of individual users. To date, very few prescriptive studies have addressed the forecast-value problem at the level of markets or sectors. Descriptive studies have been undertaken at all levels, from the level of individual users to the levels of user groups, economic sectors, and even national economies. However, such studies usually have derived their forecast-value

estimates at these higher levels simply by scaling up the estimates obtained at the individual level (i.e., by multiplying representative individual-level forecast-value estimates by the number of users).

At the level of individual users prescriptive studies have involved both hypothetical users in prototypical situations as well as typical or representative users in real-world situations. These studies have considered situations involving both single-stage and multiple-stage decision-making problems. Studies of prototypical problems have been concerned primarily with static and dynamic versions of the familiar cost-loss ratio situation (e.g., Thompson, 1962; Murphy, 1977; Katz and Murphy, 1990). Although it is relatively simple (even in its dynamic version), the cost-loss ratio situation possesses many of the essential features of real-world decision-making problems. As such, this and other prototypical problems provide reasonable frameworks within which to investigate a variety of issues related to forecast use and value, including the nature of the relationship between forecast quality and forecast value.

Several relatively realistic prescriptive case studies of the value of climate forecasts in real-world situations have been conducted since 1980 (e.g., Brown et al., 1986; Mjelde et al., 1988; Mjelde et al., 1993; Wilks and Murphy, 1986). The forecast-sensitive situations considered in these studies have consisted largely of agricultural decision-making problems, such as whether or not to plant a crop (fallowing versus planting), which crop to plant (corn versus wheat), or which of several crop-production strategies to adopt (amount of fertilizer, planting density, etc.). These studies have involved the formulation of both static and dynamic decision-making models, and they have provided quantitative estimates of forecast value over a wide spectrum of time ranges. Positive forecast-value estimates have been reported in almost all such studies, with the magnitudes of these estimates depending on a variety of factors related to the determinants of forecast value (see Section A). It is important to note that even seasonal forecasts, with their relatively great uncertainty and modest skill (generally speaking, seasonal forecasts are only slightly less uncertain and slightly more accurate than forecasts based solely on climatological probabilities), have been found to be of positive value to some users in specific situations.

Only a handful of prescriptive studies of the value of climate forecasts have been conducted at the market (or sector) level. Not surprisingly, the results of these studies do not as yet provide a very clear picture of the benefits that can be expected at this level. On the one hand, a recent study of this type (Adams et al., 1993) indicates that improved forecasts of El Nino events could provide substantial benefits to the agricultural sector in the southeastern U.S. On the other hand, earlier market-level studies (e.g., Babcock, 1990; Lave, 1963) suggest that producers of some commodities in the agricultural sector may not benefit from improvements in the quality of forecasts. In fact, these studies suggested that, due to price effects, the economic welfare of producers could be *adversely* affected by enhanced forecast quality. To the extent that these latter studies properly capture the complexities inherent in market-level assessments, they appear to underline the potential dangers inherent - in at least some situations - in estimating the value of forecasts at the market or sector level on the basis of scaled-up estimates derived at the level of individual users.

Descriptive case studies have been conducted in a relatively wide spectrum of settings (see Stewart, 1994). For example, this body of work includes regional, national, and international assessments involving many sectors or user groups as well as studies focused on a specific sector or user group. Most studies in this category have been based on surveys of - or interviews with - selected users. The quality of these studies - and their forecast-value estimates - vary considerably. Many studies of this type (as well as other studies in the descriptive category) do not actually provide quantitative forecast value estimates.

Those descriptive studies that have produced quantitative estimates of the benefits of forecasts generally have found the forecasts of interest to be of positive value. In fact, many descriptive studies of the survey/interview type have yielded very large forecast-value estimates at the user-group, sector, and/or national level. However, it is important to keep in mind that these estimates usually have been derived by scaling up estimates obtained at the level of individual users. In some cases, these scaled-up estimates are based on positive responses from a relatively small fraction of the total number of individual users contacted.

In addition to providing estimates of the socio-economic value of forecasts, prescriptive studies have explored the relationship between forecast quality and forecast value (see Katz and

Murphy, 1994). Since quality is a basic determinant of value (see Section A), an understanding of the nature of quality/value relationships can provide insight into the way in which future changes in forecast quality can be expected to affect forecast value. It has been demonstrated, in both prototypical and real-world studies, that quality/value relationships are inherently nonlinear. This nonlinearity may be reflected in a quality threshold below which the forecasts of interest are of no value and/or in a nonlinear functional relationship above this threshold. Moreover, in some situations, these relationships are characterized by convex functions, thereby implying that forecast value will increase at an increasing rate as forecast quality improves. The nature and characteristics of such quality/value relationships clearly warrants further investigation.

Other studies in this general category have investigated the conditions under which forecasts produced by one forecasting system can be judged to be better - in terms of both quality and value - than forecasts produced by another forecasting system (e.g., Ehrendorfer and Murphy, 1988). Related work has demonstrated that increases in specific aspects of forecast quality (e.g., accuracy, skill) do not necessarily guarantee increases in value for all users of forecasts. Specifically, due to the fact that a multivalued relationship generally exists between individual aspects of forecast quality and forecast value, increases in accuracy (for example) actually can be accompanied by decreases in value for some users (e.g., Murphy and Ehrendorfer, 1987, 1994).

C. Tentative Conclusions and Current Problems

Several tentative conclusions can be drawn from this review of the body of literature currently available concerning the socio-economic value of climate forecasts:

1. The results of both prescriptive and descriptive studies indicate that state-of-the-art forecasts generally possess positive value over a broad spectrum of decision-making problems and forecast time ranges. Moreover, improvements in forecast quality are usually associated with increases in forecast value. (Note: Caveats regarding the reliability of some forecast-value estimates are noted in Section A.)

2. Forecast use and value depends on the nature and structure of users' decision-making problems, on various characteristics of the information (including the forecasts) on which their decisions are based, and (in the case of descriptive studies) on a variety of behavioral characteristics of users.

3. To date, the vast majority of prescriptive studies of the benefits of climate forecasts have focused on obtaining forecast-value estimates at the level of individual users. This work has produced some notable developments concerning assessment methods (e.g., dynamic models) and has enhanced the level of understanding of some assessment issues (e.g., quality/value relationships). In addition, it has created a small cadre of relatively experienced forecast-value assessment researchers. However, greater efforts need to be made to model the forecast-sensitive situations of interest in a realistic manner and to undertake applications in sectors other than agriculture.

4. Very few studies have been conducted at the market or sector level that have not explicitly or implicitly involved the assumption that forecast-value estimates at those levels can be obtained by scaling up estimates obtained at the level of individual users. Although this simple process of aggregating benefits may give reasonable estimates in some situations, it is unlikely to be appropriate in most real-world situations. A prescriptive approach that makes use of economic models of markets or sectors - or an approach that combines decision-analytic and economic models - appears to offer the best hope of addressing this market-level assessment problem in a methodologically sound manner.

5. Most real-world case studies of the socio-economic benefits of forecasts or the incremental benefits associated with improvements in forecast quality have not explicitly addressed the issue of the costs of producing/improving the forecasts. To ascertain whether or not it is desirable (in a socio-economic sense) to invest in a forecasting system, or its improvement, it is necessary to take the costs of producing and/or improving the forecasts into account. Comparison of the benefits with the costs (or internalizing the costs in the benefits assessment process) provides a basis for putting the benefits into proper perspective.

6. Almost all case studies of the socio-economic value of climate forecasts have been conducted in the developed world. This state of affairs is due in large measure to the availability of models, data, etc., that are applicable to the problems of interest as well as to the presence of individuals experienced in forecast-value assessment methods. Nevertheless, a clear need exists to extend these studies into the developing world, where - in the case of climate forecasts in particular - substantial benefits are perhaps more likely to be realized.

In addition to the issues raised by the tentative conclusions discussed above, several specific problems can be identified that require further study in this context:

1. The appropriateness of alternative assumptions regarding the nature of users' prior information and the impacts of these assumptions on forecast-value estimates. For example, it is often assumed that users base their decisions on climatological information in the absence of forecasts. Under what conditions is this assumption appropriate? What are some reasonable alternatives to this assumption?

2. The impacts of temporal dependence in the climate - and in climate forecasts - on forecast-value estimates. Most assessments of the value of climate forecasts undertaken to date have ignored this temporal dependence (i.e., they have assumed that the period-to-period climate itself, as well as climate forecasts, are independent).

3. The effects of users' attitudes toward risk on forecast-value estimates. Most case studies undertaken to date have assumed that users are risk neutral; in effect, that their preferences for the consequences (of their decisions) can be described adequately in monetary terms. However, this assumption may not be appropriate in many situations; for example, most decision makers in situations involving potentially large monetary gains or losses have been shown to possess a relatively strong aversion to risk, and risk aversion may significantly affect forecast-value estimates. Ideally, the user's attitude toward risk should be investigated and then taken into account in all forecast-value studies.

4. The interactions between forecasts on different time ranges and the implications of these

interactions for forecast-value estimates. Some forecast-sensitive problems in which long-range forecasts are of primary interest also are influenced by short-range forecasts. In general, however, the impact of these short-range forecasts has been ignored. Moreover, in many forecast-sensitive problems involving short-range forecasts, users' decisions may also be sensitive to long-range forecasts. To obtain realistic overall estimates of the value of weather/climate forecasts, it is necessary to take into account all of the forecast information that influences users' decisions.

5. The effects of characteristics of climate forecasts other than quality on forecast-value estimates. Many features of forecast information in addition to forecast quality may influence forecast value. Such features include forecast lead time (the time between a forecast's issuance and the beginning of its valid period), forecast format (e.g., nonprobabilistic or probabilistic), and forecast specificity (the number of distinct forecast values or categories), as well as the spatial and temporal resolution of the forecasts. The impacts of these characteristics warrant further investigation in future forecast-value studies.

Other problems that could be added to this list include a host of issues related to the actual behavior of users in real-world decision-making problems and the impacts of these behavioral characteristics on forecast use and value.

In conclusion, two particular points must be emphasized with respect to current and future efforts to assess the value of climate forecasts. First, this problem is fundamentally an interdisciplinary problem, requiring expertise from such fields as economics, operations research, psychology, statistics, and systems analysis, as well as climatology. Second, the problem of forecast-value assessment requires - to make real progress - a *continuing* program of methods-oriented and applications-oriented research. Real progress in this area - in the sense of developing sound assessment methods that can produce reliable and credible estimates of the value of climate forecasts - will require that resources are made available to attract and retain an interdisciplinary forecast-value assessment team (or two) over an extended period of time.

D. Acknowledgments

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Part II

Short List of Collected Works

Introduction

This section of the report contains a short list of books, conference proceedings, preprint volumes, and reports that contain collections of chapters or papers on the socio-economic value of forecasts. In some cases, individual items from these collections are included as separate entries in Part III.

Short List of Collected Works

Anonymous, 1993: *First European Conference on Applications of Meteorology*. Oxford, United Kingdom, unpaged.

Atmospheric Environment Service, 1992: *Fifth International Meeting on Statistical Climatology*. Toronto, Ontario, Canada, AES, pp. J58-J71 and J91-J102.

European Space Agency, 1984: *Nowcasting II - Mesoscale Observations and Very-Short-Range Weather Forecasting*. Paris, France, ESA SP-208, pp. 491-520.

Katz, R.W., and A.H. Murphy, Editors, 1994: *Economic Value of Weather and Climate Forecasts*. Cambridge, United Kingdom, Cambridge University Press, in press.

Krasnow, R., Editor, 1986: *Policy Aspects of Climate Forecasting*. Washington, DC, Resources for the Future, RFF Proceedings, pagination unknown.

Mitre Corporation, 1980: *Proceedings of Cimate and Risk Conference*. McLean, Virginia, Mitre Corporation, pagination unknown.

Murphy, A.H., and D.L. Williamson, Editors, 1977: *Weather Forecasting and Weather Forecasts: Models, Systems, and Users*. Boulder, Colorado, National Center for Atmospheric Research, Summer Colloquium Notes (1976), pp. 524-662.

National Academy of Sciences, 1981: *Managing Climatic Resources and Risks*. Washington, DC, NAS Press, 51 pp.

Royal Meteorological Society, 1979: *Proceedings of Conference on Value of Meteorological Services* (Melbourne). Melbourne, Australia, RMS, Australian Branch, Report, 197 pp.

Taylor, J.A., Editor, 1970: *Weather Economics.* Elmsford, New York, Pergamon Press, 126 pp.

Taylor, J.A., Editor, 1972: *Weather Forecasting for Agriculture and Industry.* Cranbury, New Jersey, Associated Universities, 250 pp.

University of Wisconsin, 1971-1975: Multidisciplinary studies of the social, economic, and political impact resulting from recent advances in satellite meteorology. Madison, University of Wisconsin, Space Science and Engineering Center, Reports: Volumes 1-6, 459 pp., 431 pp., 252 pp., 199 pp., 280 pp., and 100 pp., respectively.

Various authors, 1982: Various titles. *Journal of Applied Meteorology,* 21, Number 4 (April), pp. 447-539.

World Meteorological Organization, 1990: *Economic and Social Benefits of Meteorological and Hydrological Services.* Geneva, Switzerland, WMO - No. 733, 461 pp.

World Meteorological Organization, 1991: *Extended Abstracts Submitted to the ICTP/WMO International Technical Conference on Long-Range Weather Forecasting Research.* Geneva, Switzerland, WMO/TD No. 395, pagination unknown.

Part III

Annotated Bibliography

Introduction

Part III consists of an annotated bibliography containing a list of 130 books, papers, and reports. The key to the annotation appears in Part IIIA and the bibliography itself constitutes Part IIIB. (Note: During the period that this report was written the author did not have access to a number of the items included in this bibliography. Thus, some references and annotations are unavoidably incomplete and some references/annotations may be in error in one or more respects. The author would welcome the receipt of information that could improve the completeness and/or accuracy of the bibliography.)

A. Key to Annotation

Group A - Approach/Method

Prescriptive [P]

- micro-level/decision-analytic/prototypical [idp]
- micro-level/decision-analytic/real-world [idr]
- macro-level/economic [ae]
- simulation [s] (micro-level or macro-level)

Descriptive [D]

- survey [s]
- decision experiment [d]
- other [o]

General [G] (e.g., presciptive/descriptive, expository, socio-economic impacts)

Group B - Type/Range of Forecasts

Weather forecasts/short-range [ws] (≤ 1/2 week)

Weather forecasts/medium-range [wm] (1/2-2 weeks)

Climate forecasts [c] (> 2 weeks)

Both types/all ranges [wc]

Non-specific type/range [n]

Group C - Sector of Application

Agriculture [a] (including forestry)

Construction [b]

Energy [e]

Public health and safety [h]

Recreation [r]

Transportation [t]

Water resources [w]

Non-specific [n]

Multiple sectors [m] (as in national assessments)

Notes: The annotations appear in boldface at the end of each item in the bibliography. The groups of annotations are separated by a slash (/).

B. Bibliography

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Adams, R.M., K.J. Bryant, B.A. McCarl, D.M. Legler, J.J. O'Brien, and A. Solow, 1993: The value of improved ENSO forecasts: an example from U.S. agriculture. Report to Economics Group, Office of the Chief Scientist, NOAA, 54 pp. **Pae/c/a**

Agnew, C.E., and R.J. Anderson, 1977: The economic benefits of improved climate forecasting. Princeton, New Jersey, Mathematica, Inc., Technical Report, 159 pp. **Pae/c/a**

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Anderson, L.G., and J.M. Burnham, 1973: Application of economic analysis to hurricane warnings to residential and retail activities in the U.S. Gulf of Mexico coastal region. *Monthly Weather Review*, **101**, 126-131. **Pidr/w?/m**

Babcock, B.A., 1990: The value of weather information in market equilibrium. *American Journal of Agricultural Economics,* **72**, 63-72. **Pae/n/a**

Baquet, A.E., A.N. Halter, and F.S. Conklin, 1976: The value of frost forecasting: a Bayesian appraisal. *American Journal of Agricultural Economics,* **58**, 511-520. **Pidr/ws/a**

Bergen, W.R., and A.H. Murphy, 1978: Potential economic and social value of short-range forecasts of Boulder windstorms. *Bulletin of the American Meteorological Society,* **59**, 29-44. **Ds/ws/h**

Bramshill Consultancy Limited, 1993: Study on the direct economic effects of the METEOSAT programme. Basingstoke, Hants, U.K., Final Report (ESA Contract #10106/92/F/HEW), 114 pp. plus one appendix. **Ds/wc/m**

Brown, B.G., R.W. Katz, and A.H. Murphy, 1986: On the economic value of seasonal-precipitation forecasts: the fallowing/planting problem. *Bulletin of the American Meteorological Society,* **67**, 833-841. **Pidr/c/a**

Brown, B.G., and A.H. Murphy, 1987: The potential value of climate forecasts to the natural gas industry in the United States. Chicago, Illinois, Gas Research Institute, Final Report GRI-87/0239, 191 pp. **Ds/c/e**

Brown, B.G., and A.H. Murphy, 1988: On the economic value of weather forecasts in wildfire suppression mobilization decisions. *Canadian Journal of Forest Research,* **18**, 1641-1649. **Pidr/ws/a**

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